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Executive Summary

The Institute for Defense Analyses (IDA) has developed, within the context of the Risk Assessment and Mitigation Framework for Strategic Materials (RAMF-SM), a method for estimating the quantities of strategic materials associated with U.S. imports of parts and end-items that contain these strategic materials. These quantities are often referred to as embedded materials: they are embedded in imported goods, so United States industry does not need to use that amount of material to produce those goods. This paper presents some background information, describes the estimation methodology, and presents a set of such estimates based on the data used to support the analyses for the *Strategic and Critical Materials 2015 Report on Stockpile Requirements* (U.S. Department of Defense, 2015).

Contents

1. Background

The United States government maintains a National Defense Stockpile (NDS) of strategic and critical non-fuel materials. Established in the World War II era, the NDS has been managed by the Department of Defense (DOD) since 1988. By law, DOD is required to submit periodic reports to Congress stating which materials, and in what amounts, the stockpile should contain. The most recent such report as of this writing is the *Strategic and Critical Materials 2015 Report on Stockpile Requirements* (U.S. Department of Defense, 2015), hereafter referred to as the 2015 Requirements Report. The Risk Assessment and Mitigation Framework for Strategic Materials (RAMF-SM), developed by the Institute for Defense Analyses (IDA), comprises a suite of models and databases used to support the analyses underlying these reports.[1]

RAMF-SM is a multi-step process. This paper is primarily concerned with Step 2 of RAMF-SM, which models the determination of shortfalls of materials in a specified planning scenario, often a national emergency. RAMF-SM Step 2 itself has a number of substeps. Of interest here are the first three of those substeps:

- Substep 2a determines the U.S. demands for goods and services, and the corresponding demand for outputs from U.S. industry, that would occur in a certain specified national emergency. These demands are developed via economic modeling, with adjustments as necessary to model the specific characteristics of the national emergency scenario.
- Substep 2b determines the demands for materials, i.e., the amounts of materials that U.S. industry needs to produce output that will satisfy the demands computed in substep 2a.
- Substep 2c determines the available supply of materials, taking into account the characteristics of the particular national emergency scenario examined. It then compares those supplies with the material demands from substep 2b and computes material shortfalls.

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[1] For more information on RAMF-SM, see James S. Thomason, et al., IDA Paper P-5190, *Analyses for the 2015 National Defense Stockpile Requirements Report to Congress on Strategic Materials*, Institute for Defense Analyses, Alexandria, VA, August 2015; and Thomason, et al., IDA Document D-5432, *An Overview of Step 2 of the Risk Assessment and Mitigation Framework for Strategic Materials (RAMF-SM)*, Institute for Defense Analyses, Alexandria, VA, March 2015.

Substeps 2a and 2b constitute the RAMF-SM methodology for estimating the raw strategic materials the United States needs. This methodology can be adapted to identify the materials associated with U.S. imports of parts and end-items in a given scenario, as described in detail in the following section.

2. Methodology

A. Introduction

The United States makes use of strategic and critical materials (S&CMs) in two main ways:

- Raw material is consumed by U.S. industry to manufacture usable finished goods (parts and end-items).
- Material is contained in imports of finished goods, or is used abroad in the production of finished goods that are then imported by the United States. (Material in this category can be referred to as embedded material demand.)

Each of these ways represents material used to satisfy U.S. demand, and therefore must be considered in determining U.S. demand for materials. The RAMF-SM process is designed to estimate how much raw material United States industry will need in specific scenarios. Accounting for embedded material demand is an integral part of RAMF-SM substep 2b, but the amounts have not been reported explicitly in the Requirements Reports. This paper shows how the embedded demand is computed within RAMF-SM.

A tacit assumption is made that domestic demand for goods (and services) is considered essential. Whatever amount is not met by imports must be produced by U.S. industry; demand is not allowed to go unfulfilled. Another assumption is that U.S. industry has the necessary capacity to produce whatever goods and services are not met through imports.[2]

B. Material Consumption Ratios

The key parameters in determining embedded material demand are material consumption ratios (MCRs), which also play a key role in RAMF-SM substep 2b. Generally speaking, industries produce their output, while consuming raw material in the

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[2] The Forces Mobilization Model (FORCEMOB), one of the components of RAMF-SM, can model the process of building new industrial capacity that might become necessary in a national emergency. For more information on FORCEMOB, see Eleanor L. Schwartz, et al., IDA Paper P-2953, *Documentation of the Forces Mobilization Model (FORCEMOB), Versions 3.1 and 3.2, Volume I: General Description*, and *Volume II: Data Preparation Guide*, Institute for Defense Analyses, Alexandria, VA, January 1996; also Robert J. Atwell, et al., IDA Document D-5433, *Forces Mobilization Model (FORCEMOB): Unclassified Training Tutorial*, Institute for Defense Analyses, Alexandria, VA, August 2015.

process. The MCR specifies the amount of material (in mass units, such as tons) consumed by a given industry in producing a specified dollar amount (generally, a billion dollars) of its output. A major part of this material might end up in the output product itself, but the MCR could also include material used in necessary manufacturing machinery or material that is wasted. A separate MCR is computed for each combination of material of interest (51 of the materials studied for the 2015 Requirements Report have associated MCRs) and industry sector (the economic models partition the U.S. economy into 360 industry sectors).[3]

The MCRs are computed based on material consumption information (usually from the Department of Commerce or the U.S. Geological Survey) and economic output information from the INFORUM economic databases.[4] Before describing how MCRs are used to compute embedded material amounts, let us review RAMF-SM's modeling of material and industrial flow.

C. Flows of Material and Industrial Output

Figure 1 depicts the flow of material as modeled in RAMF-SM Step 2. To avoid making the figure too cluttered, the meanings of the flows along the various arcs are not shown in the figure itself, but instead explained in the text following the figure. Note that flows along arcs 1 through 4 are expressed in mass units (e.g., tons) of material, while flows along arcs 7 through 10 are expressed in millions or billions of dollars' worth of end-items.

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[3] The economic data and models are obtained from the Inter-industry Forecasting Project at the University of Maryland (INFORUM). Two major models are used in RAMF-SM substep 2a: LIFT (Long-term Inter-industry Forecasting Tool) (Meade, 2001) and ILIAD (Inter-industry Large-scale Integrated and Dynamic model) (Meade, 2011). INFORUM also provides several different sets of historical economic data, which are used in various portions of substeps 2a and 2b.

[4] A summary description of how the MCRs are constructed is as follows: One starts with information on consumption amounts of raw material by U.S. manufacturers in recent years (available from the Department of Commerce and the U.S. Geological Survey). The consumption is apportioned among the industrial sectors of the economic model. The economic databases give the dollar amount of output of each industrial sector in recent years. Dividing the consumption amount for an industry by that industry sector's output yields the MCR, which is a measure of how much material a sector needs to produce a dollar's worth of its output. A more mathematical description of the procedure appears in IDA Document D-5477, Eleanor L. Schwartz, *Computation of Material Demand in the Risk Assessment and Mitigation Framework for Strategic Materials (RAMF-SM) Process*, Institute for Defense Analyses, Alexandria, VA, September 2015.

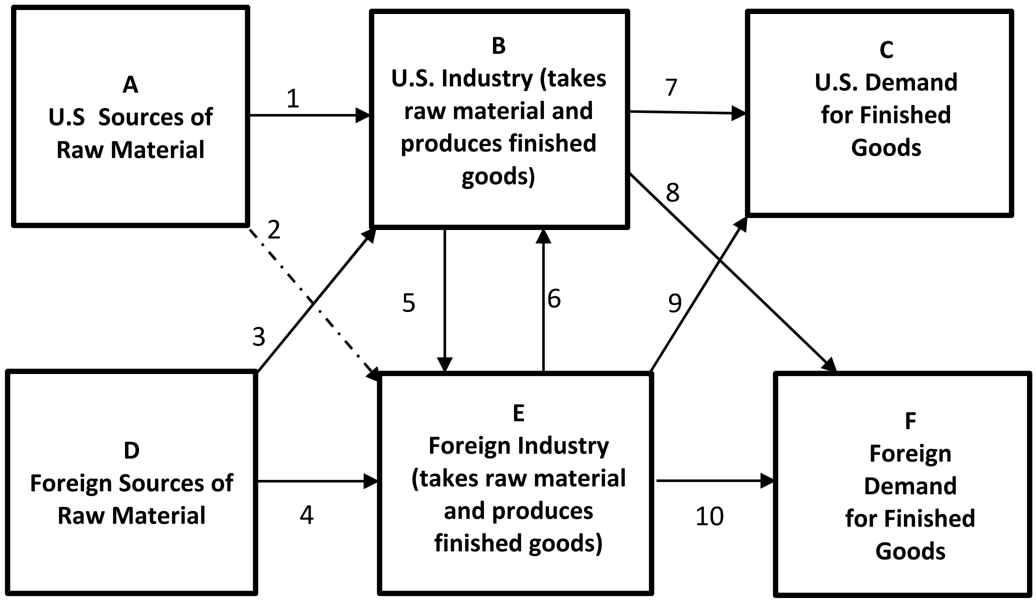

Figure 1. RAMF-SM Step 2 Material and Industrial Output Flow

- Arc 1 represents U.S. raw material available for use by U.S. industry. This is a key quantity for the Computation of Material Shortfalls portion of RAMF-SM (substep 2c), and is known in that context as U.S. supply.
- Arc 2 represents U.S. raw material exported to other countries. It is shown as a dashed line because in a national emergency, all U.S. supply is considered to be available to U.S. industry if needed; exports of raw material are not explicitly modeled.
- Arc 3 represents amounts of foreign raw material potentially available to the United States. This is also a key quantity for the material shortfall computation process and is known in that context as available foreign supply. In general, the United States can count on obtaining only a certain fraction (the "market share") of foreign raw material. In a national emergency, it might receive less than that amount because of supplier country adversary status, unreliability, and other such factors.[5]
- Arc 4, foreign raw material that goes to foreign countries, is not explicitly modeled, but can be thought of as corresponding to material not included in the U.S. market share.

[5] The complete list of decrement and delay factors, in addition to market share, include supply adversary status, degradation in ability to supply, anti-U.S. sentiment, war damage, and shipping losses. These parameters all vary by country of origin. For more information, see IDA P-5190 (Thomason, et al., 2015).

- Arcs 5 and 6, flows between U.S. and foreign industries, are included here because they happen in actuality, but are not explicitly modeled at the aggregation level of RAMF-SM. Incorporation of the flows represented by these arcs would be necessary for any detailed disaggregation of the stages of material processing that would rely upon material transfer to or from the United States.
- Arc 7 represents U.S.-manufactured finished goods used in the United States, and that satisfy U.S. demands.
- Arc 8 represents U.S.-manufactured finished goods that are exported. Peacetime or steady-state exports are forecast by economic models. In the national emergency scenario, they are generally decremented from their peacetime levels so that items formerly exported can be available to satisfy domestic needs. The sum of arcs 7 and 8 represents the output of U.S. industry.
- Arc 9 represents U.S. imports of finished goods, or equivalently, foreign-produced goods exported to the United States. These imports play a key role in the shortfall computation process. Peacetime or steady-state imports are forecast by economic models. In a national emergency scenario, they are decremented from their peacetime levels to account for supplier country unreliability and other factors.[6]
- Arc 10 represents foreign-manufactured finished goods that are not exported to the U.S. RAMF-SM does not explicitly model them.

Actually, RAMF-SM Step 2 is somewhat more disaggregated than Figure 1 in that it often treats different foreign countries separately, instead of amalgamating them into a single "foreign" source. But for purposes of this paper, the more aggregated figure will suffice.[7] The two-level distinction, "raw material" vs. "finished goods," is admittedly aggregated. A more detailed model might expand Figure 1 to explicitly consider various stages of material processing (e.g., mining, smelting, alloying, casting/forging/rolling, manufacture of parts, and manufacture of finished goods), and the transfer of material between U.S. and foreign processors (in both directions) at different stages.

D. Material Demands, MCRs, and Embedded Demand

The U.S. demands for goods and services indicated in the upper right-hand box of Figure 1 (which is marked as Box C) are all considered essential.[8] They are treated as

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[6] The same decrement and delay factors applied to material imports (Arc 3) are also applied to imports of goods and services (Arc 9).

[7] U.S. demand is also divided into defense, civilian, and emergency investment categories.

[8] The preparation process for the Base Case national emergency scenario used for the Requirements Report explicitly deems as essential only a portion of the forecast civilian demand, and includes only

given demands that must be met, either by U.S. production or by imports. If some imports of foreign goods are cut off because of the various decrement factors applied to supplier countries, then the corresponding demands must be met by U.S.-manufactured products. Consequently, the demands can be partitioned into those met by imports and those met by U.S. industrial production.[9]

Although the MCRs are computed based on U.S. material consumption and economic data, U.S. and foreign production processes are assumed to be similar enough that the MCRs remain valid for foreign production. Thus, a given dollar amount of output in a given industry requires the MCR times that dollar amount of raw material to produce, whether that production occurs in the United States or abroad.

The material required to produce the goods and services demanded by the United States (i.e., Box C in Figure 1) is computed by multiplying the MCRs by the demand amounts (material by material, industry sector by industry sector). This can be partitioned into material amounts needed by U.S. industry in its production processes to satisfy domestic demand (Arc 7 in the figure) and the embedded material associated with imports. The embedded material is computed by multiplying the amount of imports (Arc 9 in the figure) by the appropriate MCRs.

To repeat: the embedded material is computed by multiplying the amount of imports (Arc 9 in the figure) by the appropriate MCRs. That is the main point of this paper.

U.S. industry also needs material to produce the goods destined for export. The overall amount of material needed by U.S. industry in its production processes is then determined as:

MCR × [Total industrial output needed to satisfy U.S. demand (Box C)

+ U.S. industrial output used to produce goods for export (Arc 8)

– foreign industrial output that produced imported goods (Arc 9)]

(Algebraically, this is also equal to the MCR multiplied by the sum of Arc 7 and Arc 8.) This computation is performed separately for each combination of material of interest and industry sector.

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that portion in the calculations. A peacetime case, such as that presented in the next section, can be regarded as one in which all the civilian demand is to be considered as essential. (Defense demands are always considered as essential.)

9 It is assumed (at the RAMF-SM level) that the U.S. has the manufacturing capability to produce the increased quantity of products, but will need additional raw material in order to do so. (If the amount of available raw material is insufficient, then the model computes and reports a shortfall.)

3. Specific Findings

Of the strategic materials analyzed for the 2015 Requirements Report, 51 have associated material consumption ratios (MCRs), and it is thus possible to estimate material embedded in imports via the methodology discussed in the previous section. Table 1 (see page 11) displays material estimates in a peacetime, or steady-state scenario taking place in the time frame 2017-2020.[10] The underlying demands for goods and services, imports, and exports are projected by the INFORUM models to be consistent with the Council of Economic Advisers' forecast of the economy as of mid-2013.

First, Table 1 provides estimates of the quantities of these materials likely to be used by the United States itself to produce essential end-items. These estimates are shown in the column of the table marked A. The approximate dollar value of those materials is shown in column B.

Column C provides estimates of the quantities of these materials that would plausibly be used by foreign producers to build the parts and end-items that the U.S. is expected to import in the scenario. Column D provides the approximate dollar value of those materials shown in column C.

Column E, which is the sum of columns A and C, provides the total amount of each strategic material estimated to be used (either in the United States or abroad) to produce essential parts and end-items used by the United States in the scenario. Column F provides the approximate dollar value of those materials shown in column E.

Column G provides an estimate of the percentage of the total material usage by the United States in the scenario associated with imports of parts and end-items.

It is evident that these percentages vary somewhat, from 17% for aluminum-lithium alloys to 55% for natural rubber. The 17% figure, however, is a low outlier. Of the 51 materials listed in Table 1, 41 have an embedded imports percentage value (column G)

[10] Table 1 is based on data that form the peacetime equivalent to the Base Case national emergency scenario that underlies the 2015 Report to Congress. The Base Case differs from the peacetime case in that it: 1) includes a conflict scenario with associated requirements to regenerate weapons lost and expended in that scenario; 2) decrements imports due to conflict-related supplier country unreliability; 3) decrements exports based on policy decisions; 4) excludes civilian demand that is deemed nonessential; and 5) includes emergency investment demand. Detailed description of the assumptions underlying the Base Case are documented in the 2015 Requirements Report and in IDA Paper P-5190 (Thomason, et al., 2015).

between 35% and 55%. The average proportion (dollar weighted) is about 44%, similar to the unweighted average (43%) and the median (45%). The low outliers (aluminum-lithium alloys, noted above, and chromium metal, with a value of 19%) warrant further examination.

As mentioned in the Methodology section, the estimates provided in Table 1 assume that material usage in the foreign production processes is the same or similar to U.S. material usage. If foreign MCR data should become available, they could be used instead of U.S.-based MCRs in applying this methodology.

All estimates in Table 1 are specific to this particular peacetime case. Similar estimates could be produced for the Base Case. A comparison of estimates for the two cases could be instructive, in particular, because imports of goods and services from hostile or unreliable countries are decremented in the Base Case scenario. This tends to lead to lower embedded material in general (and more demands for material use by U.S. industry). Certain specific materials might be more strongly affected by these decrements.

Table 1 follows.

Table 1. Embedded Imports Summary, 2015 Peacetime Case (2017-2020)

			A	B	C	D	E	F	G
			Raw Material Needed by U.S. Manufacturers		Material Associated with Imports		Total Material Amount		Percent associated with imports
	Material Name	Units	in units	in $M	in units	in $M	in units	in $M	
1	Aluminum Lithium Alloys	metric tons	16,629	238.29	3,466	49.66	20,094	287.95	17.25%
2	Aluminum Oxide Fused Crude	short tons	1,466,558	745.05	1,283,392	651.99	2,749,950	1,397.04	46.67%
3	Antimony	short tons	155,739	1,321.00	92,262	782.58	248,000	2,103.58	37.20%
4	Beryl Ore	short tons	34,114	66.54	22,933	44.73	57,047	111.27	40.20%
5	Beryllium Copper Master Alloy	short tons	40,012	634.50	36,560	579.76	76,573	1,214.26	47.75%
6	Beryllium Metal	short tons	265	218.22	222	182.71	487	400.93	45.57%
7	Bismuth	Pounds	10,217,474	108.82	7,631,685	81.28	17,849,159	190.09	42.76%
8	Boron	MT Oxide	15,087,382	25,459.96	8,338,078	14,070.51	23,425,460	39,530.46	35.59%
9	Cerium	MT Oxide	12,500	65.62	9,325	48.96	21,825	114.58	42.73%
10	Chromium Ferro (Ferrochromium)	short tons	3,120,326	5,367.56	2,503,656	4,306.77	5,623,981	9,674.32	44.52%
11	Chromium Metal	short tons	35,346	296.90	8,239	69.21	43,585	366.11	18.90%
12	Cobalt	pounds Co	134,133,985	1,810.81	61,995,433	836.94	196,129,418	2,647.75	31.61%
13	Columbium	pounds Cb	110,348,189	2,102.23	52,222,926	994.89	162,571,115	3,097.13	32.12%
14	Dysprosium	MT Oxide	184	85.61	169	78.53	353	164.14	47.84%
15	Erbium	MT Oxide	46	4.60	30	2.97	75	7.58	39.24%
16	Europium	MT Oxide	432	399.16	361	333.69	792	732.85	45.53%
17	Fluorspar Acid Grade	short tons	3,630,712	1,004.59	1,964,306	543.51	5,595,018	1,548.09	35.11%
18	Fluorspar Metallurgical Grade	short tons	280,682	63.66	240,158	54.47	520,840	118.12	46.11%
19	Gadolinium	MT Oxide	48	2.24	41	1.91	89	4.15	46.00%
20	Gallium	kilograms	230,575	63.41	200,307	55.08	430,881	118.49	46.49%
21	Germanium	kilograms	256,587	327.15	252,862	322.40	509,449	649.55	49.63%
22	Graphite	metric tons	1,443,046	2,096.75	1,006,209	1,462.02	2,449,255	3,558.77	41.08%
23	Indium	metric tons	679	515.87	581	441.24	1,259	957.12	46.10%
24	Iridium (Platinum Group)	troy oz.	295,662	295.47	265,779	265.61	561,441	561.08	47.34%
25	Lanthanum	MT Oxide	26,084	299.97	21,075	242.36	47,159	542.32	44.69%
26	Lead	short tons Pb	9,092,302	20,976.98	7,706,482	17,779.73	16,798,784	38,756.71	45.88%

Table 1. Embedded Imports Summary, 2015 Peacetime Case (2017-2020) Concluded

			A	B	C	D	E	F	G
			Raw Material Needed by U.S. Manufacturers		Material Associated with Imports		Total Material Amount		Percent associated with imports
	Material Name	Units	in units	in $M	in units	in $M	in units	in $M	
27	Lithium	metric tons	10,000	345.94	5,584	193.18	15,584	539.12	35.83%
28	Magnesium	metric tons	990,725	4,422.95	1,172,690	5,235.31	2,163,415	9,658.27	54.21%
29	Manganese Ferro (C and Si)	short tons	2,833,683	2,566.92	1,734,077	1,570.83	4,567,760	4,137.75	37.96%
30	Manganese Metal-Electrolytic	short tons	111,985	290.04	60,200	155.92	172,185	445.96	34.96%
31	Manganese Ore Chem/Metal Grade	short dry tons	2,787,719	12.43	2,251,034	10.04	5,038,752	22.47	44.67%
32	Minor Rare Earths (Ho Tm Yb Lu)	MT Oxide	10	7.40	8	5.90	17	13.31	44.37%
33	Neodymium	MT Oxide	2,015	136.00	1,767	119.30	3,782	255.30	46.73%
34	Nickel	short tons Ni	1,375,656	23,037.58	871,589	14,596.16	2,247,244	37,633.74	38.78%
35	Palladium (Platinum Group)	troy oz.	15,614,714	12,655.73	16,472,752	13,351.17	32,087,466	26,006.89	51.34%
36	Platinum (Platinum Group)	troy oz.	6,153,049	8,909.61	4,953,970	7,173.35	11,107,019	16,082.96	44.60%
37	Praseodymium	MT Oxide	926	113.43	804	98.47	1,730	211.90	46.47%
38	Quartz Crystals (synthetic)	metric tons	206	35.01	244	41.41	450	76.42	54.19%
39	Rhenium	Pounds	621,111	760.86	423,821	519.18	1,044,931	1,280.04	40.56%
40	Rubber (natural)	long tons	6,951,743	14,210.70	8,474,508	17,323.52	15,426,251	31,534.22	54.94%
41	Samarium	MT Oxide	131	1.18	109	0.98	241	2.17	45.43%
42	Silicon Carbide	short tons	977,416	722.31	730,786	540.05	1,708,202	1,262.36	42.78%
43	Strontium	metric tons Sr	101,226	139.86	107,629	148.70	208,855	288.56	51.53%
44	Tantalum	pounds Ta	8,199,293	1,506.25	7,334,637	1,347.41	15,533,930	2,853.66	47.22%
45	Tellurium	metric tons	257	27.62	214	23.01	471	50.62	45.45%
46	Terbium	MT Oxide	35	28.57	31	25.56	66	54.13	47.22%
47	Tin	metric tons	237,536	5,564.65	159,154	3,728.45	396,690	9,293.10	40.12%
48	Tungsten	pounds W	230,665,076	3,113.98	131,951,957	1,781.35	362,617,033	4,895.33	36.39%
49	Vanadium	short tons V	33,775	687.56	21,251	432.61	55,026	1,120.18	38.62%
50	Yttrium	MT Oxide	844	13.51	680	10.89	1,524	24.39	44.63%
51	Zinc	short tons	5,986,688	10,784.18	4,024,964	7,250.41	10,011,652	18,034.59	40.20%
	Total Dollar Value			154,665.22		119,966.67		274,631.89	43.68%

Appendix A
Illustrations

Figure

Table

Appendix B
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Appendix C
Abbreviations

IDA	Institute for Defense Analyses
DOD	Department of Defense
FORCEMOB	Forces Mobilization Model
ILIAD	Interindustry Large-scale Integrated and Dynamic Model
INFORUM	Interindustry Forecasting Project at the University of Maryland
LIFT	Long-term Interindustry Forecasting Tool
MCR	Material Consumption Ratio
NDS	National Defense Stockpile
RAMF-SM	Risk Assessment and Mitigation Framework for Strategic Materials
S&CM	Strategic and Critical Material

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13. SUPPLEMENTARY NOTES

14. ABSTRACT

The Institute for Defense Analyses (IDA) has developed, within the context of the Risk Assessment and Mitigation Framework for Strategic Materials (RAMF-SM), a method for estimating the quantities of strategic materials that are associated with U.S. imports of parts and end-items that contain these strategic materials. These quantities are often referred to as embedded materials: they are embedded in imported goods, so United States industry does not need to use that amount of material to produce those goods. This paper presents some background, describes the estimation methodology, and presents a set of such estimates based on the data used to support the analyses for the *Strategic and Critical Materials 2015 Report on Stockpile Requirements* (U.S. Department of Defense, 2015).

15. SUBJECT TERMS

strategic materials, critical materials, National Defense Stockpile, Defense Logistics Agency, methodology, material consumption

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